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The effects of sign design features on bicycle pictorial symbols for bicycling facility signs

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ABSTRACT

The inanimate bicycle symbol has long been used to indicate the animate activity of bicycling facility signs. In contrast, either the inanimate bicycle symbol or the animate bicycle symbol has been used interchangeably for the standard pavement symbols in bike lanes. This has led to confusion among pedestrians and cyclists alike. The purpose of this study was to examine two different designs (inanimate symbol vs. animate symbol) involved in the evaluation of perceived preference and glance legibility, and investigate sign design features on bicycle pictorial symbols. Thirty-five participants compared current bicycle signs (inanimate symbols) to alternative designs (animate symbols) in a controlled laboratory setting. The results indicated that the alternative designs (animate symbols) showed better performance in both preference and glance legibility tests. Conceptual compatibility, familiarity, and perceptual affordances were found to be important factors as well.

1. Introduction

Bicycling is one of the most popular recreational activities and is also an important method of transportation for local commuting. Compared to the use of motor vehicles, bicycling has many advantages such as low cost and significant health benefits. Importantly, bicycling also produces zero pollutants and helps reduce traffic congestion. However, increasing numbers of bikes on the road have heightened the need to make bicycling safer and more accessible. The national government's Federal Highway Administration (FHWA) has promoted various programs to increase bicycling safety and accessibility, including shared-use paths, pedestrian and bicycle information centers, and via the establishment of the National Center for Safe Routes to School. In particular, the "shared-use paths program" is expected to increase bicycling opportunities through the more than 11,000 miles of paths superimposed on railroad corridors that continue to expand across the nation (Pedestrian and Bicycle Information Center, 2010).

In 2009, 630 bicyclists were killed and an additional 51,000 were injured in motor vehicle traffic crashes (NHTSA, 2009). Although these numbers have decreased from a 2005 high of 786 fatalities, and given the underreporting of bicycle accidents and injuries (Elvik and Mysen, 1999), continuous efforts are required to make roadways safer for bicyclists (Paustenbach, 2009). Since bicycle-related signage plays an important role in providing traffic information, the current standards should be assessed and validated for their efficacy. Up to now, roadway signs have featured the inanimate bicycle symbol (the "riderless" bicycle) for portraying the animated and vigorous activity of bicycling. In the case of standard pavement symbols in bike lanes, both the inanimate bicycle symbol and the animate bicycle symbol (bicycle with a rider) have been used interchangeably. This variability has led to a lack of cohesion and consistency in bicycle-related signs, which could result in a failure to communicate the desired information.

Traffic signs are one of the most important components of a transportation system in that they help guide, regulate and warn road users—drivers, bikers, and pedestrians—of possible hazards. Pictorial symbols have been widely used in traffic signs since they can effectively convey complex information using limited resources, for example, shape, size, and color. Moreover, as research has confirmed, pictorial symbols are more easily identifiable than words from a greater distance (Collins and Lerner, 1982), and support better performance of memory tasks compared to text (Paivio, 1986). Pictorial symbols also provide safety and risk information that is more inclusive, providing cyclists with graphical cues rather than verbal cues (Smith-Jackson et al., 2010). Similarly, well-designed pictorial symbols convey hazard information rapidly and with less mental workload on recipients (Smith-Jackson, 2006).

However, pictorial symbols are not always designed to be easily understood and recognized (Collins et al., 1982; Wolff and

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Wogalter, 1993). In fact, pictorial symbols that are poorly designed can actually convey misleading information, resulting in frustration or even more serious consequences such as threats to safety and health (Laughery and Wogalter, 2006; Rogers et al., 2000). A number of studies of these symbols have investigated issues of comprehension and legibility, particularly with respect to the effects of various factors, e.g., driver characteristics, sign design features, cultural differences, and the ergonomic principles of the design (Ben-Bassat and Shinar, 2006; Ng and Chan, 2008; Shinar et al., 2003; Young and Wogalter, 1990).

With regard to current problems in bicycle-related signs, the most critical aspect is that the pictorial symbols in use today do not always correspond to the intended message of the sign. In other words, a bicycle symbol depicting a bicycle without a rider could be interpreted in several ways depending on the symbol used and the location. While it could indeed convey the intended message—that a driver should expect to share the road with bicyclists—it could also be interpreted as a location for a bicycle parking place, or a bicycle store or repair shop. Several studies have explored the importance of context in pictorial symbol design. Bazire and Tijus (2009) proposed a framework for understanding road signs, and showed that natural categories (categories used by drivers) are not consistent with legal categories (categories defined in legal texts about driving), thus pointing to the confusion that can result from context-related issues. Wolff and Wogalter (1998) also emphasized the effect of context in the evaluation of pictorial symbol comprehension, with the primary variable being either the absence or presence of photographs depicting the probable environments where a symbol would be seen. Their study confirmed that context is important for providing important cues that result in increased comprehension. Therefore, given the rising popularity of bicycling, it is imperative to assess current bicycle pictorial symbols to ensure the efficacy of these signs.

The purpose of this study was to investigate the effectiveness of sign design features that comprise bicycle pictorial symbols for bicycling facility signs. Current bicycle signs were compared to alternative designs regarding perceived preference in a controlled laboratory setting. Glance legibility was also examined. These findings are expected to provide useful information and recommendations to design more effective bicycle signs.

2. Method

2.1. Design

Laboratory experimentation was used to determine the effects of sign designs on participants' preferences, using a within-subjects design. Quantitative values were obtained using preference rankings, and, following the preference test, open-ended questions were administered to gauge the participants' opinions of most/least preferred signs. In the glance legibility test, the effects of symbol (10), size (5), and color (2: positive and negative contrast) on the percentage of correct answers in each condition were examined using a within-subjects design.

2.2. Participants

Thirty-five participants were recruited for this study. Of these, 21 were male and 14 were female. The mean age of the participants was 19.7 years (SD $=$ 1.41; Min $=$ 18, Max $=$ 23). Participants were recruited through the experiment management system of the Psychology Department at Virginia Tech. All participants received one research credit for participation.

The participants were limited to individuals who (1) were greater than 18 years of age, (2) had minimum visual acuity of 20/20 or better in both eyes with or without correction, and (3) had normal color vision (self-report of no color blindness or cataracts). Prior to beginning the experiment, participants' visual acuity was tested by using the Snellen Eye Chart. All participants were licensed automobile drivers. Sixteen participants (46%) self-identified as frequent drivers (daily), and 19 participants (54%) as occasional drivers (two times a week or less).

2.3. Materials

The current bicycle-related signs were first seen in a 1979 manual produced by the FHWA, known as the "Manual on Uniform Traffic Control Devices." The symbol, seen in Fig. 1(a), is a standalone bicycle image with significant details (e.g., handlebars, implied frame-lines within the wheels, and seat). For comparison purposes, this study reviewed existing bicycle-related signs and selected national recreation signs developed by the Society for Environmental Graphic Design (SEGD) as the alternative bicycle signs since signs' design features were compatible with the purpose of this study. The three images, shown in Fig. 1(b), feature a simpler bicycle design, but include a helmeted rider.

A 17-in. LCD monitor with 1280 $\times$ 1024 resolution was used to present the stimuli (signs) for both preference and glance legibility tests. The images of the signs were developed as precisely-sized vector files using Adobe Illustrator software. The images were shown to the participants using Adobe Acrobat 9 Pro to maintain fidelity while controlling size, timing and intermediate images between stimuli projections.

In the preference test, participants were asked to compare the current bicycle sign with three alternative designs by identifying the most preferred sign. Three major bicycle-related sign applications were tested: bicycling, bicycle warning, and no bicycling. Two motorcyclist signs were included to serve as distracters. In terms of four other bicycle-related applications (i.e., pedestrian and bicycler crossing, hill, and bicycle surface conditions), an alternative design was designed and tested with the current bicycle signs. Participants were asked to give preference rankings for each question based on perceived preference. In addition, the participants' reasoning was solicited via open-ended questions regarding most/least preferred symbols. In the preference test, participants were required to sit in front of the LCD monitor. The distance between the LCD monitor and a participant's position was approximately 2 ft (60 cm) with image frames containing symbols that were 1.5″ (38 mm) across and above the visual threshold.

In the glance legibility test, 10 symbols, 5 sizes, and 2 colors were examined. Among the 10 symbols utilized, two were current bicycle signs and 3 alternative designs. The remaining 5 symbols were not bicycle symbols but were included as distracters in order to prevent participants from memorizing the bicycle symbols.

2.4. Procedure

Upon entering the lab, participants completed an informed consent document and demographic questionnaire, which included visual acuity, color vision deficiency, and driving experience. Prior to beginning the study, participants' visual acuity was

(a) (b)

Fig. 1. Current bicycle signs (a) and alternative bicycle signs (b).

Table 1
Mean rankings of the various pictorial symbols in different applications.

Comparison between the current bicycle sign and alternative designs						
Application	Pictorial symbols					
Bicycling	2.34	1.57	2.80	3.43	5.14	5.71
Bicycling warning	2.86	1.49	2.71	3.17	4.91	5.86
No bicycling	2.14	1.74	3.09	3.29	5.11	5.63

examined using the Snellen Eye Chart. Those who met the minimum visual acuity standard (20/20) were allowed to continue on to the experiment. Participants participated in both the preference test and the glance legibility test. The preference test was always performed first. Participants were not timed; they were given sufficient time to determine their preferences and describe their reasoning.

In the glance legibility test, participants were required to sit in a fixed position. The distance between the LCD monitor and the participant's position was 20 ft (600 cm), which was designed to replicate 20/20 visual acuity with mid-sized symbols in the 5 sizes. To remove potential distractions, all non-related objects in the experimental space were covered with white sheets. Each symbol was displayed for one second on the LCD monitor, and between displays, an abstract roadway image was displayed in order to remove any iconic memory within the eye. After projection of each display, participants were asked to identify the same symbols using reference card. The order of the 10 symbols was randomized progressively by size, beginning with the smallest series of 10 symbols, and transitioning to the next series of larger symbol size. Half of the participants examined the positive contrast format first (white on green), while the other half tested the negative contrast format first (black on yellow). The average time required to complete the experiment was approximately 60 min.

3. Results

3.1. Preference

The mean rankings for all conditions are shown in Table 1. A lower mean ranking indicates higher preference. In all conditions, one of the three alternative designs (the bicycle symbol with a rider, handlebars, and implied bicycle frame within the wheels) was preferred to the current "riderless" bicycle sign.

A Shapiro–Wilk test of normality was conducted to determine the distribution of the dependent variables. All distributions were non-normal. Consequently, non-parametric tests were conducted for subsequent analyses. A Friedman test (two-way non-parametric ANOVA) was used to determine whether there were significant differences between rankings of symbols in each question. Results indicated that there were significant differences among the rankings of the six signs in three applications, $p < 0.0001$. Additional post-hoc paired comparisons using Z tests showed that there were significant differences between the current bicycle sign and the alternative sign only in the bicycling warning application (Fig. 2). Apart from that single application, no significant differences between the current bicycle sign and alternative designs in bicycling and no-bicycling applications were observed.

Participants' opinions on most preferred signs from the open-ended question were qualitatively analyzed using thematic analysis to identify the common reasons of participants' preference. The qualitative results in Table 2 represent participants' responses and redundant responses were emitted. Participants' responses, such as 'most representative of a person riding a bike' were based on the actual words reported by participants to describe the reason of their preference. In addition, the percentage and number of participants choosing each sign were noted. For example, in the bicycling application, 13 participants preferred the current bicycle sign, whereas 19 participants preferred one of alternative bicycle designs (the one featuring a handlebar and implied bike frame) and 3 participants preferred the other alternative bicycle designs among total 35 participants.

With respect to sign applications for pedestrian and bicycler crossings, hills, and bicycle surface conditions, participants also preferred the alternative design. The qualitative results from participant responses are shown in Table 3.

3.2. Glance legibility

The percent of correctly-chosen symbols in each condition was calculated to use as the legibility fraction (Table 4). A mixed model ANOVA with symbol, series, and color was used to test differences in the model, as well as group differences accounting for variance in legibility. Two effects were found to be statistically significant: symbol, $F_{(9,\ 306)} = 44.74$, $p = 0.0001$ and series, $F_{(4,\ 136)} = 49.15$, $p = 0.0001$. With regard to color (positive or negative contrast), there was no significant effect. To determine which of ten symbols were significantly different, post-hoc paired comparisons were conducted using a least squares difference test. The results revealed differences in alternative designs and the current bicycle symbol. In terms of the series, responses were significantly different from each other, which describes decreased legibility along with decreased symbol size. In particular, the results showed that the current bicycle symbol has greater detrimental effect on legibility than the alternative designs. For example, the current bicycle symbol (sign 1) showed 14% (green: series 1) and 57% (green: series 2) of correctly answered results, while the alternative design (sign 2) had 71% (green: series 1) and 80% (green: series 2) of correctly answered results on Table 4.

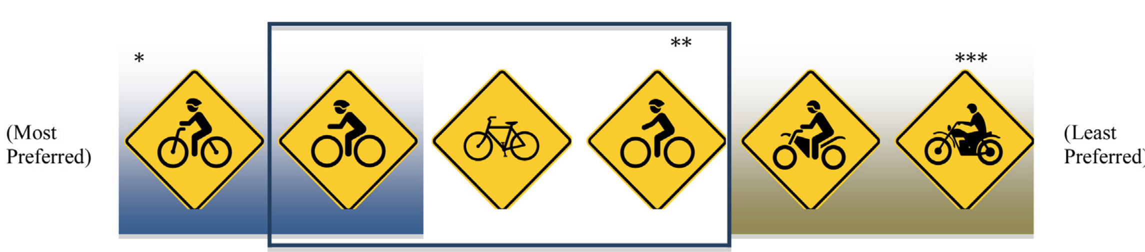

Fig. 2. Paired comparison results (signs in same box are not significantly different).

Table 2
Summary of qualitative results.

Application	 <The current bicycle sign>		 <The most preferred alternative sign>	
	% (*N*) of participants	Representative responses	% (*N*) of participants	Representative responses
Bicycling	37% (13)	Simple, easy to notice, very clear	54% (19)	Clear, appealing, most representative of a person riding a bike, easy to identify bicycle route
Bicycling warning	26% (9)	Most accurate representation of a bicycle, simple and easy to understand	60% (21)	Clearly looks like a bike and is easily recognizable, helmet and handlebars visible
No bicycling	51% (18)	Clear prohibition sign, simple to understand that no bikes are allowed, most readily identifiable	46% (16)	Most accurate representation, complete picture of a bike and biker, detailed representation of bike, recognizable symbols, easy to identify, the red line across the bike symbol doesn't block it out of view

4. Discussion

In general, the results of this study indicate that the alternative design (the bicycle symbol with a rider, handlebars, and implied frame within the wheels) performed better in both the preference test and the glance legibility test. Several interesting trends were also identified.

In the preference test, the alternative bicycle design (the bicycle symbol with a rider, handlebars, and implied bicycle frame within the wheels) was the most preferred (Fig. 3), with the current bicycle sign (the riderless bicycle symbol) the next most preferred in all three applications (bicycling, bicycling warning, no bicycling). Although the difference between the alternative symbol and the current symbol was statistically significant only with the bicycling warning application among three applications (bicycling, bicycling warning, no bicycling), the fact that the alternative symbol was the most preferred across all applications has important implications. The qualitative results from the open-ended questions also validated that the alternative design (the bicycle symbol with a rider, handlebars, and implied bicycle frame within the wheels) helped participants clearly understand the fundamental meaning of bicycle signs.

Table 3
Response results from the pedestrian and bicycler crossing, hill and bicycle surface condition applications.

Application	Pictorials	% (Number) of participants	Representative responses
Pedestrian and bicycler crossing		72% (25)	Simple, clear, has enough space between the bicycle and pedestrian to easily distinguish between the two; presence of the dotted line gives drivers clear notice of pedestrian crossing
		28% (10)	Descriptive, easy to identify, better description of what is going on, clear illustration
Pedestrian and bicycler crossing		100%(35)	Both pedestrian and bicycle are separately illustrated, easier to infer the two pictures. The other sign looks like a person pushing a bike—not as a pedestrian but a rider.
		0%(0)	
Hill		86% (30)	There is an actual rider on the bike The steep platform effectively shows a downhill force and possible danger.
		14% (5)	Simple and to the point, looks most like a bicycle and is more recognizable.
Bicycle surface condition		77% (27)	Rider is present and involved in the sign, rather than just a detailed bicycle, simple and fast to comprehend, bold and noticeable
		23% (8)	Looks most like a real bike, better detail, less detail on the rider and more focus on the slippery road, lines are clearer without a rider present

Table 4
The percentage of correctly answered in each condition.

		Green						Yellow					
		Series						Series					
		1	2	3[a]	4	5	Mean	1	2	3[a]	4	5	Mean
1		14%	57%	60%	43%	71%	49%	29%	46%	57%	66%	77%	55%
2		71%	80%	80%	83%	94%	82%	69%	71%	69%	89%	89%	77%
3		63%	77%	74%	80%	89%	77%	51%	60%	77%	71%	77%	67%
4		77%	77%	83%	83%	86%	81%	77%	80%	71%	94%	89%	82%
5		63%	80%	94%	91%	97%	85%	66%	77%	83%	91%	91%	82%
6		26%	37%	51%	74%	83%	54%	37%	57%	69%	74%	83%	64%
7		77%	83%	91%	97%	97%	89%	63%	91%	91%	91%	98%	87%
8		60%	83%	86%	89%	89%	81%	43%	86%	89%	91%	89%	79%
9		14%	40%	37%	49%	49%	38%	23%	29%	43%	43%	66%	41%
10		43%	43%	37%	60%	66%	50%	26%	43%	43%	51%	60%	45%
Total (mean)		51%	66%	69%	75%	82%	69%	48%	64%	69%	76%	82%	68%

[a] Series 3 is to replicate 20/20 visual acuity.

There are several possible explanations for this finding. First, the pictorial symbol of a rider on a bicycle allowed participants to grasp the essential meaning about the action of bicycling, which is the fundamental communicative intent of bicycle-related signs. In comparing participant responses about the current bicycle sign vs. the alternative design, participants who chose the alternative design suggested that it resembled a bike rider; those who chose the current sign said it depicted a bike more realistically. Therefore, the bicycle sign with a rider is suggested to have better conceptual compatibility with the intended information to be conveyed. Conceptual compatibility refers to the extent to which codes and symbols are meaningful to those who must use them (Ben-Bassat and Shinar, 2006; Shinar et al., 2003).

Second, the fact that the current bicycle sign was the second most preferred symbol may have something to do with familiarity. To reiterate, there were no significant differences in mean rankings between the current bicycle sign and the alternative design (the most preferred one) except in the bicycling warning application among the three applications (bicycling, bicycling warning, no bicycling). Since the current bicycle signs have been in use since

Fig. 3. The most preferred bicycle signs and current signs in preference test by mean rank.

(High percentage of correct answers) (Low percentage of correct answers)

Fig. 4. The results of legibility test.

1979, this study's participants—all of whom were born after that year and have a driver's license—were accustomed to seeing them. Accordingly, familiarity may have influenced participants' preferences. This outcome confirms the findings of Easterby and Hakiel (1981), who demonstrated the effects of familiarity on participant performance (e.g., comprehension). McDougall et al. (1999) also found high associations between meaningfulness and familiarity, even if the symbol did not match the given meaning. Thus, despite the influential effects of familiarity, the fact that participants preferred the alternative design to the current bicycle sign should be considered meaningful.

Third, noteworthy inferences can be made about participants' reasoning from their responses. The study confirmed that among the alternative designs, the one featuring a handlebar and implied bike frame (lines within the wheels) was selected by participants as being the most understandable. In fact, they preferred this symbol to other alternative designs. This finding implies that handlebars and lines within bicycle wheels could provide perceptual affordances for movement and use. The concept of affordance was originated by Gibson (1979) to explain the properties of the environment with which an actor (people or animal) interacts, and has been widely adopted as important design factors (Hartson, 2003; Norman, 1988). Therefore, our study confirmed that handlebars and lines within bicycle wheels should be used to enhance comprehension of bicycle signs.

Moreover, participants mentioned that the addition of the helmet on the rider was an important feature for promoting bicycle safety. This observation validates the findings of the Insurance Institute for Highway Safety (IIHS), which reported that 92 percent of pedal cyclists killed in 2007 were riding without helmets (IIHS, 2007). Therefore, considering the importance of wearing a helmet in preventing cycling fatalities, the image of a helmet should be considered an essential design component in bicycling symbols.

With respect to our findings from the glance legibility test, the alternative design showed higher percentage of correctly answered results than the current bicycle signs. The alternative signs (shown in Fig. 4, left) were 20% more legible than the current sign (Fig. 4, right). In particular, for Series 1 (smallest size), the alternative designs were 34% more legible than the current sign. This has significant implications for roadway safety: the earlier the detection of traffic signs, the easier it is for a driver or a bicyclist to engage or discard essential information.

Although this study identified several meaningful results, further investigation is needed with respect to the effects of a rider symbol on bicycle signs. This study was conducted in a controlled laboratory setting, which provided preliminary evidence of the value of an alternative bicycling design. However, complex road traffic situations may make it difficult to generalize our laboratory findings. Therefore, a similar study should be undertaken in actual driving conditions to corroborate the perceived effectiveness of an alternative design.

5. Conclusion

Traffic signs play a vital role in creating a safer environment for drivers, bikers, and pedestrians. Although inanimate bicycle signs have been the standard for over 30 years, this study confirms that animate bicycle symbols should be considered in the redesign of bicycling facility signs. This study's findings—particularly if they are tested in actual driving situations—may justify the need to incorporate animate bicycle designs in signage with the goal of enhancing the safety of drivers and bicyclists alike.

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